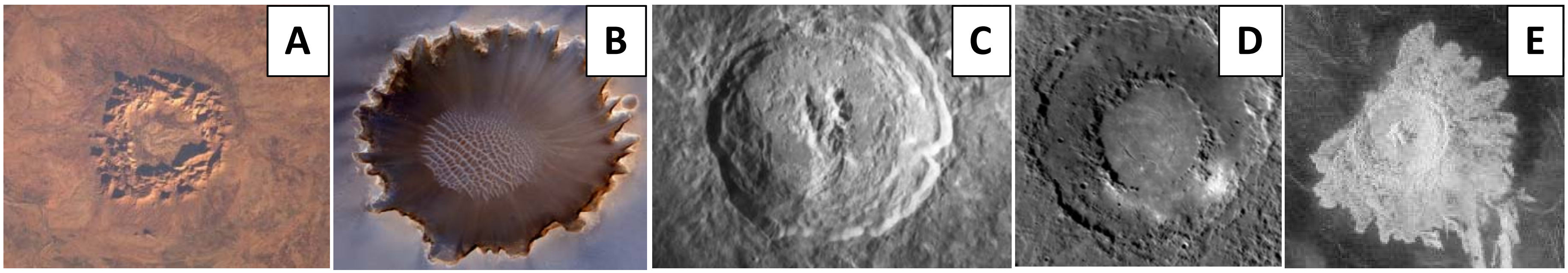
CRATER COMPARISONS

Earth and Planetary Impact Craters

Part 1: Identifying Crater Characteristics

The images below are of impact craters from different planetary worlds in our Solar System. List your observations in the space below. Focus your observations on similarities and differences of the visible characteristics of these features.



SIMILARITIES	DIFFERENCES

Based on your observations of the above images, list at least 1 question you have about impact craters in the space below?

Background Information

Causes of Impacts

Impact craters are features created on the surface of a planetary body when a meteoroid strikes the surface creating a bowl-shaped hole. Meteoroids can be particles of cosmic dust, parts of asteroids or leftover material from the formation of our Solar System, or event comets – objects made of rock and ice that travel through our solar system. Small meteoroids burn up in our atmosphere. Those that are large enough to make it through our atmosphere, strike the surface creating an impact crater. The number of impact craters found on the surface of a planet varies, as do the size of these features. Asteroids and fragments of other planets are the most common objects that are the meteorites we find on earth.

Meteoroid: A chunk of rock or ice orbiting the Sun inside the Solar System

Meteor: What we see when a meteoroid attempts to pass through Earth's atmosphere.

Meteorite: Left over material that survives the trip through the atmosphere and is found on the surface.

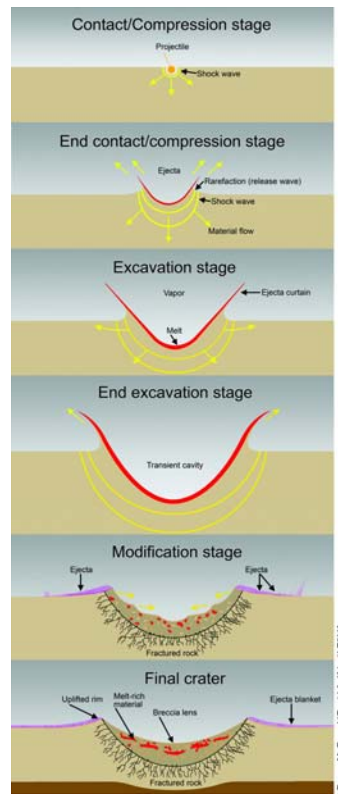


Image Credit: LPI

Believe it or not, you have probably seen hundreds of impact craters! Every time you look up at the Moon you are looking at evidence of ancient collisions in our Solar System. As a matter of fact, impact craters are found on most of the rocky (terrestrial) planets and moons in our Solar System. The impact process is the most common process seen across our Solar System.

Formation of Craters

There are a number of stages involved in the formation of craters. First, we have a contact/compression stage. This is when a meteorite (a meteoroid that has successfully made it throughout atmosphere) traveling 10-15 kilometers per second strikes the surface of a planet. As it strikes, shock waves compress the surface and cause rocky material to almost liquefy or melt. The excavation state is when material gets ejected or thrown out of the newly formed hole in the ground. The modification stage is when the ejecta settles out onto the surface and material in the walls of the newly formed crater slump. The final crater will continue to be modified by gravity and erosion. The entire crater formation process occurs in seconds and usually the meteoroid is vaporized. Fragments that remain are called meteorites.

Crater Characteristics

There are 5 main parts or characteristics of a crater. These include:

- **Central peak:** An uplifted mound in the floor of the crater.
- **Wall:** The sides of the crater.
- **Floor:** The bottom of the crater.
- **Rim:** The raised area around the edge of the crater.
- **Ejecta:** The material from inside the crater that was thrown our during the impact event. Ejecta appear as rays or sometimes as a blanket of material surrounding the crater.

As show below, the difference between a simple crater and complex crater is that a complex crater has a central peak. A central peak is created when the melted rock rebounds or gets uplifted during the impact event and then solidifies in that uplifted position. Complex craters are also larger structures and can have material that has slumped along the walls giving them a terraced or step-like appearance.

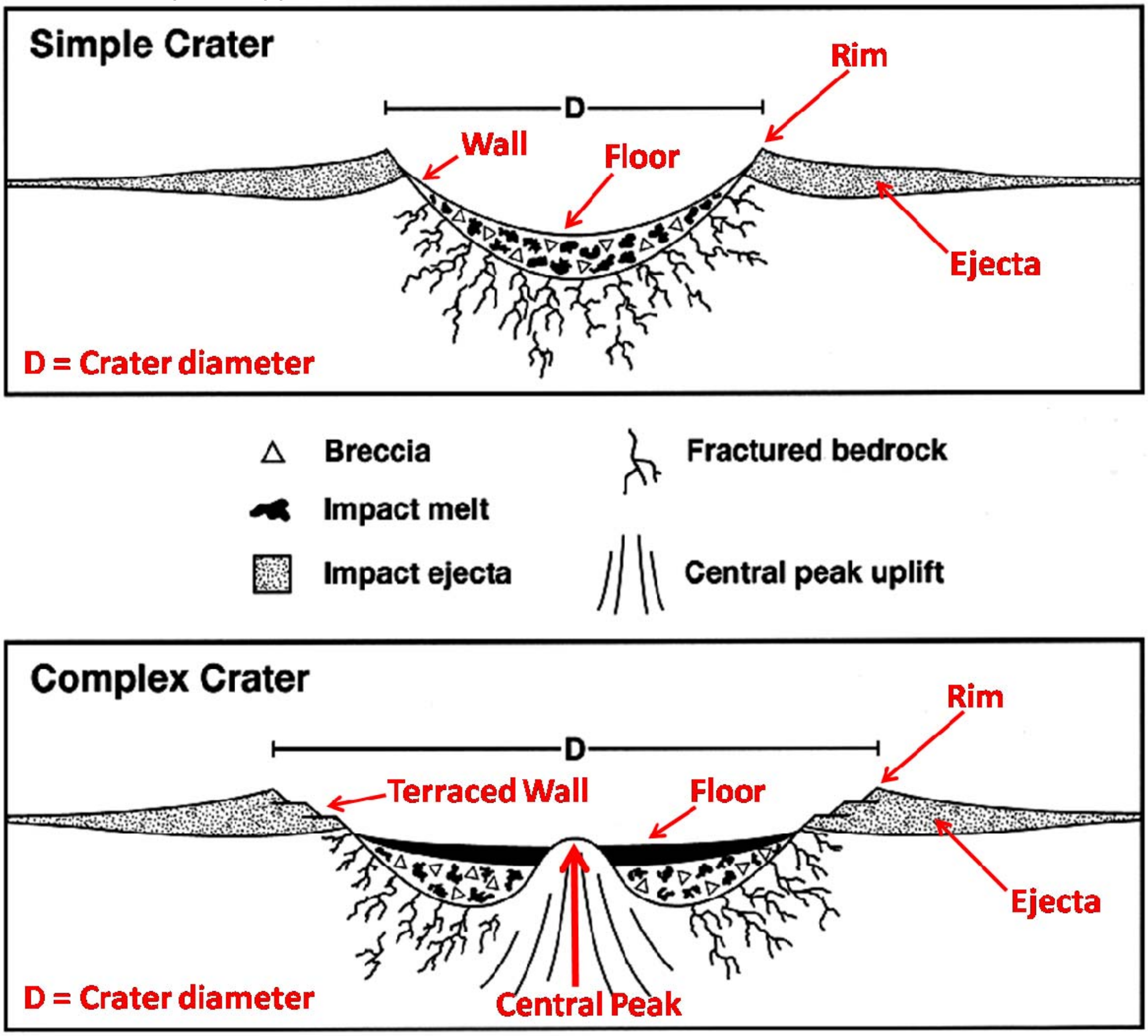


Image Credit: NASA/GSFC

What do Craters Tell Us?

Impact craters open up a window into a planet's history and geology. Once a crater is formed on a planet, making observations of how it is modified or eroded tells us a bit about that planetary world. Craters can be eroded by wind, water, tectonics, or even volcanic activity. They can be covered or filled in by water, vegetation, sediments (sand, dust, etc), landslides, lava or even ejecta from the formation of other craters.

There are a few general geologic principles or rules that enable scientists to use craters as a tool to help us understand the sequence of geologic events that took place in a region. These include:

- Principle of Superposition: This principle states that the order of layers or geologic features found on the surface provide information about which features are older or younger. Features found on top are the youngest.
- Crater Density: The more craters on the surface of a planet, the older that surface is.
- Crater Modification: The more modified a crater, the older it is. This can be dependent on the planetary surface as well as the environmental factors (geological or biological) that may influence the crater. Though this may not hold up on Earth, when looking at other planetary worlds, the relative age of craters can be determined through the classification of craters in the following categories:
    - Preserved craters = youngest, best preserved craters;
    - Modified craters = middle aged craters with evidence of some modification;
    - Destroyed craters = oldest craters that have been severely altered

Planetary Comparisons

Scientists use what they know about the formation of features on Earth to develop and test hypotheses, make inferences, and draw conclusions about what may be happening on other planetary bodies. This type of science is called comparative planetology. As scientists make planetary comparisons, they base their conclusions on their observations and interpretations, as well as what information is already known about the planet(s) they are studying. This information includes factors such as the composition of the planet, temperatures, the atmosphere (if one exists), the interior, the surface features, etc. The more knowledge scientists have about the planet as a whole, the better they can draw conclusions with supporting evidence. By conducting planetary comparisons, scientists are able to better understand the history of other planets and the processes that shape their surfaces.

INITIAL OBSERVATIONS

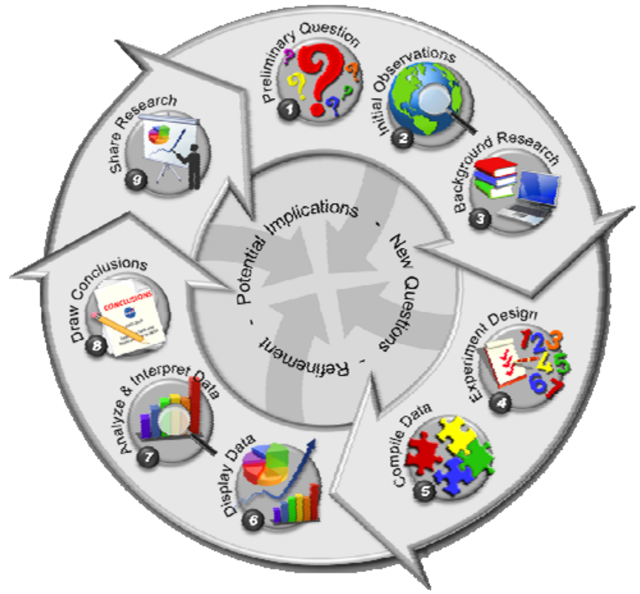
Let's look at the initial images on page 1 of this activity. These images, in the order they appear, are from Earth, Mars, Earth's Moon Mercury, and Venus. Using the table below, use a check mark to select the characteristics that are visible in each of the craters:

	Image A	**Image B**	**Image C**	**Image D**	**Image E**
Visible rim					
Visible ejecta blanket					
Smooth flat floor					
Filled in or outlined by water					
Central Uplift					
Terraced Walls					

Though it may have been difficult to clearly identify these characteristics, do you think you have enough data to answer the following question: **What are the similarities and differences between craters on Earth and other planetary worlds?** With one data point…definitely not. This activity will step you through a modest investigation to help you answer this question…though you may want to expand your research even further, to more confidently support your conclusions. Let's begin….

Part 2: Continuing Our Crater Investigation

The image shown on the right is an illustration of the process of science scientists use when conducting an investigation. So far you have asked a preliminary question (Step 1), made some initial observations (Step 2), and gained some background knowledge in the beginning part of this activity (Step 3). At this point, we are ready to move into Step 4 in the process of science. By establishing an experiment design you are creating a plan to conduct your research. By creating a solid plan, this will allow you to consistently collect and compile data, which will then allow you to display, analyze, and interpret that data in order to draw your conclusions.



The process of science

For this activity you will be introduced and guided through the remaining steps of the process of science (steps 4 – 8) as a model to help you work through this investigation. This plan will first focus on collecting data for craters on Earth. You will then continue the investigation so you can compare your findings from craters on Earth to craters on other planetary worlds.

PROCESS OF SCIENCE STEP 4: Experiment Design

In this step, it is important that you have our finalized research question and our current hypothesis. A hypothesis should be based on observations you have already made as well as any other background knowledge you may have.

Research Question: What are the similarities and differences between craters on Earth and other planetary worlds?

Hypothesis: Based on the images we have observed so far, and what we know about impact craters in our solar system, we hypothesize that…..

The following information will help drive our investigation:

1. **Image Data Collection:** We will use Crew Earth Observation Imagery of Earth retrieved by the Expedition Earth and Beyond Crater Images retrieved from the Gateway to Astronaut Photography of Earth (http://eol.jsc.nasa.gov) as well as additional data and information from the Earth Impact Database (http://www.passc.net/EarthImpactDatabase/index.html)
2. **Specific Data to Collect:** We will log the following information from each image:
   1) Image Identification #; 2) Crater name (if known); 3) Latitude (N); 4) Longitude (E); 5) Planetary Body; 6) Geographic location (country or region)
   Additional data that focus on visible observations include: 6) Crater diameter (km); 7) Central Peak (yes, no, unsure); 8)Crater Walls (smooth, terraced, none visible, not clear); 9) Rim Definition (distinctly raised, somewhat raised, barely raised, not visible); [Not visible = filled in with water or completed eroded]; 10)Crater Modification (preserved, modified, destroyed); 11) Visible Eject Blanket (yes, not, unsure); 12) Miscellaneous notes or observations; 13) Sketches of craters.
3. **Number of Images:** For starters we will log data from images of 8 different craters on Earth.
4. **Geographic Regions:** We will not focus on any particular regions
5. **Other Data Sets:** For other planetary bodies we will look at images from the Blue Marble Matches Activity in addition to other NASA images we may be able to find.
6. **Measurements:** We will make estimated measurements of craters in images based on scale bars or measurement lines provided.
7. **Sources:** Expedition Earth and Beyond Image set; Gateway to Astronaut Photography of Earth (http://eol.jsc.nasa.gov); Earth Impact Database (http://www.passc.net/EarthImpactDatabase/index.html)

It is important to log your data consistently. Notice on the data table provided, the column headings provide specific details as to the information you should log. For example, the column heading for crater diameter states "**Crater Diameter (km)**". This means that when you log the diameter of the crater you only need to include the actual diameter as a number. You do not need to include *km* with each entry. By including (km) in the column title, it signifies that all diameters logged are in km. This will allow you to later sort information on your spreadsheet if desired.

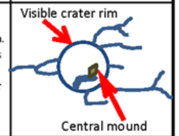
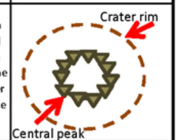
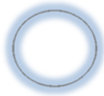
The details listed for the visible observations are very specific details that will also allow you to make common comparisons among Earth craters as well as your observations of craters on other planetary worlds. Make additions or changes as you see fit...just make sure you are consistent as you log your data.

PROCESS OF SCIENCE STEP 5: Collect and Compile Data

Shown below is a data table for craters on Earth and an additional data table to be used for observations of craters on other planetary worlds. As this research involves comparing craters on Earth with other planetary worlds, the same table headings are provided on both tables. This will allow you to make consistent comparisons of your data. Use additional paper as necessary to log your observations and data.

DATA TABLE - CRATERS ON EARTH

Please note that latitudes are provided as North latitudes [Latitude (N)]. A latitude with a (-) is a South latitude: Example: -27.8 is the same as 27.8S.
Also note that longitudes are provided as East longitudes [Longitude (E)]. A longitude with a (-) is a West longitude: Example: -68.5 is the same as 68.5W.

Image Identification #	Crater Name *(if known)*	Latitude (N)	Longitude (E)	Planetary Body	Geographic location *(country or region)*	Crater Diameter (km)	Central Peak *Yes (Y), No (N), Unsure (U)*	Crater Walls *(smooth, terraced, none visible, not clear)*	Rim Definition *(distinctly raised, somewhat raised, barely raised, not visible) Not visible = filled in with water or completed eroded*	Crater Modification *(preserved, modified, destroyed)*	Visible Ejecta Blanket *Yes (Y), No (N), Unsure (U)*	Miscellaneous notes or observations	Sketch(es) of Craters *(optional)*
ISS012-E-15881	Manicoua-gan	51.5	-68.5	Earth	Canada	51	Y	not clear	not visible	modified	N	Original diameter of crater ~100km. After erosion about 51km remains visible. "Arms"/rivers extend out from the rim. Central mound near cent/right of crater.	
ISS015-E-17360	Gosses Bluff	-23.9	132.3	Earth	Australia	22	Y	none visible	barely visible	modified	N	According to information research about this crater, the well defined bumpy circular feature is part of a central uplift. If you look closely, the rim is barely visible as a faded outer rim. This barely visible outline is the identified crater diameter.	
ISS018-E-14908	Tenoumer	22.9	-10.4	Earth	Mauritania	1.9	N	smooth	somewhat raised	modified	U	The rim of this crater looks soft. The left side in the image appears as though it is more eroded than the right side. There looks to be evidence of eroded ejecta around the rim.	

DATA TABLE - CRATERS ON ______________________

Image Identification #	Crater Name *(if known)*	Latitude (N)	Longitude (E)	Planetary Body	Geographic location	Crater Diameter (km)	Central Peak *Yes (Y), No (N), Unsure (U)*	Crater Walls *(smooth, terraced, none visible, not clear)*	Rim Definition *(distinctly raised, somewhat raised, barely raised, not visible) Not visible = filled in with water or completed eroded*	Crater Modification *(preserved, modified, destroyed)*	Visible Ejecta Blanket *Yes (Y), No (N), Unsure (U)*	Miscellaneous notes or observations	Sketch(es) of Craters *(optional)*

PROCESS OF SCIENCE STEP 6: Display Data

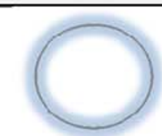
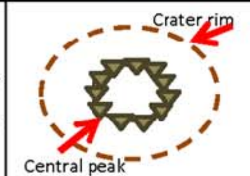
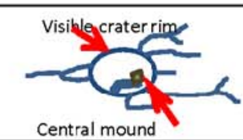
After you finish collecting and compiling your data, it is time to display your data so you can make observations of the data and later analyze the data. The three parts of this step are to: 1) Decide how to display your data (Sorted Data Table(s); Graphs, Maps, Image Illustrations); 2) Create your data displays and; 3) Make observations. See examples below.

DATA TABLES

Your completed master data table provides you with very useful information. Sorting your data is important as it allows you to look for patterns. The table below has been sorted by *crater diameter.* There are three observations listed below.

DATA TABLE - CRATERS ON EARTH

Please note that latitudes are provided as North latitudes [Latitude (N)]. A latitude with a (-) is a South latitude: Example: -27.8 is the same as 27.8S.
Also note that longitudes are provided as East longitudes [Longitude (E)]. A longitude with a (-) is a West longitude: Example: -68.5 is the same as 68.5W.

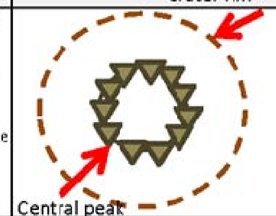
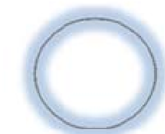
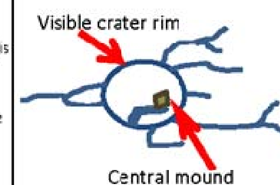
Image Identification #	Crater Name *(if known)*	Latitude (N)	Longitude (E)	Planetary Body	Geographic location *(country or region)*	Crater Diameter (km)	Central Peak *Yes (Y), No (N), Unsure (U)*	Crater Walls *(smooth, terraced, none visible, not clear)*	Rim Definition *(distinctly raised, somewhat raised, barely raised, not visible) Not visible = filled in with water or completed eroded*	Crater Modification *(preserved, modified, destroyed)*	Visible Ejecta Blanket Yes (Y), No (N), Unsure (U)	Miscellaneous notes or observations	Sketch(es) of Craters *(optional)*
ISS018-E-14908	Tenoumer	22.9	-10.4	Earth	Mauritania	1.9		smooth	somewhat raised	modified	unsure	The rim of this crater looks soft. The left side in the image appears as though it is more eroded than the right side. There looks to be evidence of eroded ejecta around the rim.	
ISS015-E-17360	Gosses Bluff	-23.9	132.3	Earth	Australia	22		none visible	barely visible	modified	no	According to information research about this crater, the well defined bumpy circular feature is part of a central uplift. If you look closely, the rim is barely visible as a faded outer rim. This barely visible outline is the identified crater diameter.	
ISS012-E-15881	Manicoua-gan	51.5	-68.5	Earth	Canada	51	yes	not clear	not visible	modified	no	The original diameter of this crater is thought to be 100km. The only visible circular structure, assumed to be the current rim of this crater, is about 51km and is filled in with water. There are "arms" (rivers) that	

Observation #1: The larger the crater diameter, the less visible the rim definition.
Observation #2: There larger the crater diameter, the more likely it is for the crater to have a central uplift.
Observation #3: Craters with a diameter over 20km appear to have a central uplift.

This table was sorted by *latitude.*

DATA TABLE - CRATERS ON EARTH

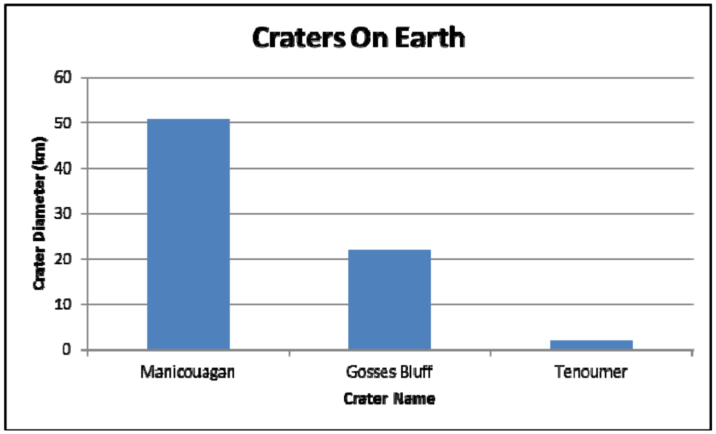
Please note that latitudes are provided as North latitudes [Latitude (N)]. A latitude with a (-) is a South latitude: Example: -27.8 is the same as 27.8S.
Also note that longitudes are provided as East longitudes [Longitude (E)]. A longitude with a (-) is a West longitude: Example: -68.5 is the same as 68.5W.

Image Identification #	Crater Name *(if known)*	Latitude (N)	Longitude (E)	Planetary Body	Geographic location *(country or region)*	Crater Diameter (km)	Central Peak *Yes (Y), No (N), Unsure (U)*	Crater Walls *(smooth, terraced, none visible, not clear)*	Rim Definition *(distinctly raised, somewhat raised, barely raised, not visible) Not visible = filled in with water or completed eroded*	Crater Modification *(preserved, modified, destroyed)*	Visible Ejecta Blanket *Yes (Y), No (N), Unsure (U)*	Miscellaneous notes or observations	Sketch(es) of Craters *(optional)*
ISS015-E-17360	Gosses Bluff	-23.9	132.3	Earth	Australia	22		none visible	barely visible	modified	no	According to information research about this crater, the well defined bumpy circular feature is part of a central uplift. If you look closely, the rim is barely visible as a faded outer rim. This barely visible outline is the identified crater diameter.	
ISS018-E-14908	Tenoumer	22.9	-10.4	Earth	Mauritania	1.9		smooth	somewhat raised	modified	unsure	The rim of this crater looks soft. The left side in the image appears as though it is more eroded than the right side. There looks to be evidence of eroded ejecta around the rim.	
ISS012-E-15881	Manicoua-gan	51.5	-68.5	Earth	Canada	51	yes	not clear	not visible	modified	no	The original diameter of this crater is thought to be 100km. The only visible circular structure, assumed to be the current rim of this crater, is about 51km and is filled in with water. There are "arms" (rivers) that extend out from the rim of the crater and in some portions, the water appears to spill into the middle of the crater. Central mound is near center/right of crater.	

Observation #1: Craters in both the southern and northern latitudes are modified.
Observation #2: Craters in both the southern and northern latitudes have central uplifts.
Observation #3: Craters in both the southern and northern latitudes have no easily detectable ejecta blankets.

GRAPHS

Graphs can allow you to visualize and illustrate your data, again allowing you to look for patterns. The graph below is showing the diameters of different craters on Earth.



Observation #1: Crater diameters on Earth, based on those observed, range from ~2km to ~50km.

Observation #2: There are not many craters of similar sizes on Earth

Observation #3: The range of craters sizes on Earth is wide.

Note: The more data you graph, the easier it is to make observations and look for notable patterns.

MAPS

Maps can allow you look for local, regional, or global patterns. The map shown here indicates the global distribution of impact craters (referred to as structures) on Earth.

Observation #1: Impact Craters are located on *most* continents on Earth.

Observation #2: The craters we observed are in North America, Africa, and Australia.

Observation #3: There are no impact craters found in Greenland or Antarctica.

World Impact Structures Sorted according to Location

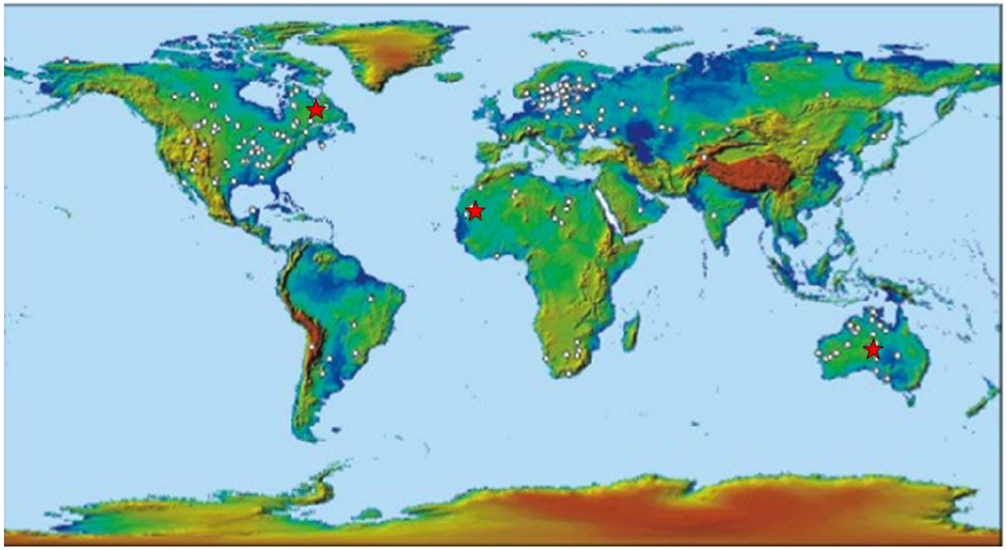


Image Credit: Earth Impact Database: http://www.unb.ca/passc/ImpactDatabase/CILocSort.html

★ = craters observed

IMAGE ILLUSTRATIONS

To help you illustrate your observations so readers of your research have a better understanding of your observations, image illustrations can be very powerful. See the two image illustration examples below.

BARELY VISIBLE RIMS

Image Illustration #1: Most craters on Earth appear to be extremely modified (eroded). Rims like the one shown in the image above are often times barely visible. (ISS014-E-11841: Oasis Crater)

CENTRAL PEAKS

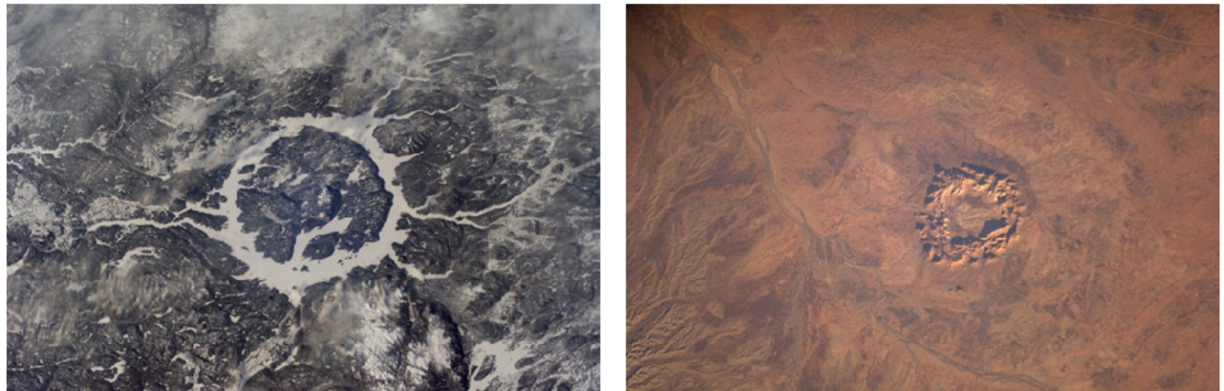


Image Illustration #2: Very few craters on Earth have central peaks. As these craters are extremely modified, the central peaks can easily go unnoticed. Original crater diameters shown here were 100km (Manicouagan ISS012-E-15881) and 22 km (Gosses Bluff ISS015-E-17360).

IMAGE ILLUSTRATION #1:

Observation #1: Image caption indicates that most craters on Earth appear to be extremely modified.

Observation #2: Crater in this image appears to be extremely eroded with hardly any visible detection of a wall, rim, or ejecta.

IMAGE ILLUSTRATION #2:

Observation #1: Central peaks in these images are very difficult to identify.

Observation #2: Craters appear to have been modified by water (and possibly ice) as well as perhaps wind or environmental factors associated with a very desert-like environment.

PROCESS OF SCIENCE STEP 7: Analyze & Interpret Data

Once you display your data and have made observations of those data displays, you are ready to do one of the most important steps of your research – analyze and interpret your data. Analysis and interpretation of data are done by thinking about how specific observations and acquired knowledge directly relate to your question. Your goal is to be able to draw conclusions about your research with supporting evidence.

As you analyze your data, focus on your research question and hypothesis.

Research Question: What are the similarities and differences between craters on Earth and other planetary worlds?

Hypothesis: Based on the images we have observed so far, and what we know about impact craters in our solar system, we hypothesize that…..

As you analyze and interpret data, focus on: 1) Specific observations from Data Displays; 2) Interpretation of what those observations mean with respect to your question/hypothesis; and 3) Evidence that support your interpretation. See samples below.

As you fill in the *Analysis and Interpretation of Data* table consider including information that focuses on each observation category you logged on your data tables. For example, you made observations of 1) crater diameter; 2) existence of central peaks; 3) crater walls; 4) rim definition; 5) crater modification; 6) visible ejecta. As a part of your conclusions, you should be able to provide evidence of the similarities and differences between craters on Earth and other planetary worlds in each of those categories.

The table on the next page provides starting information on two of these categories: c*rater modification* and c*entral peaks*. This table is not complete as it requires additional data to be collected for Earth as well as for other planetary worlds. As you look over this table, notice how the information in column 1 came directly from observations that were listed with created data displays. This is noted in parenthesis after the observation. Observations are very important in that they basically verbalize what you observe in the data display. Generally, observations should not be questionable. Everyone should be able to agree on stated observations. They are also important in your interpretation of how they relate to your research question. Your interpretation (column 2) of the observation compared to someone else's interpretation can vary. This is why it is important to have supporting evidence (column 3) to back up your interpretations, which will help you draw your overall conclusions.

ANALYSIS AND INTERPRETATION OF DATA		
Specific Observation from Data Display	**Interpretation(s) of What Observation Means with Respect to Your Question and/or Hypothesis**	**Evidence That Supports Your Interpretation** (from specific data displays and/or background knowledge)
1. CRATER MODIFICATION: Most craters on Earth appear to be extremely modified (Earth Image Illustration #1, Observation #1) Most craters on Earth's Moon appear…. Most craters on Mars… Most craters on Venus… Most craters on Mercury…	All impact craters on Earth are modified and are therefore not very recent (young). Craters on other planetary worlds vary in age. On Earth's Moon most of the craters are….meaning… On Mars most of the craters are….meaning…. On Venus…. On Mercury….	Earth has weathering and erosion processes that modify the craters on Earth. Many of these processes don't exist on other planetary worlds. Earth's Moon does not have any active processes affecting the surface so although most of these craters are preserved, most are very old. Mars….Venus….Mercury…
2. CENTRAL PEAKS: Craters with a diameter over 20km appear to have a central uplift. (Earth Data Table Observation #3); Craters with a diameter over xx km on Earth's Moon have a central uplift. Craters with a diameter of xx km on Mars have a central uplift Add info for Venus… Add info for Mercury…	The majority of impact craters on Earth are simple craters. Although there are many simple craters on other planetary worlds, there are many more complex craters. Complex craters appear to be most prevalent on….	Complex craters are generally large structures. Earth has much smaller craters than those on other planetary worlds. (See Earth Graph #1) Earth's Moon has…
3. CRATER DIAMETER… Be sure to list a specific observation you listed with one of your data displays….	Describe how this/these observations can be interpreted – what do they tell you about *crater diameter* in craters on Earth and other planetary worlds.	Provide additional supporting evidence that support your interpretation. Did you illustrate this point in another data display; did you read something about this in the text provided or somewhere else?

PROCESS OF SCIENCE STEP 8: Draw Conclusions

Now that you have completed all the above steps, you are now ready to draw conclusions about your question and hypothesis. This is an essential part of your investigation as it allows you to synthesize your overall research and state your results. It also allows others to expand or build on your research in the future.

1**. RESEARCH QUESTION:** What are the similarities and differences between craters on Earth and other planetary worlds?

Based on your research and analysis of data, what do you think is the answer to your question? Be sure to summarize supporting evidence.

2. **HYPOTHESIS:** Based on the images we have observed so far, and what we know about impact craters in our solar system, we hypothesize that…..

Based on your research and analysis of data, was your hypothesis supported or refuted? Be sure you can summarize pertinent evidence.